CLAY-BASED MATERIALS AS FIRE PROTECTION FOR TIMBER STRUCTURES

Johanna Liblik

PhD Candidate
Department of Civil Engineering and Architecture
Tallinn University of Technology, Estonia

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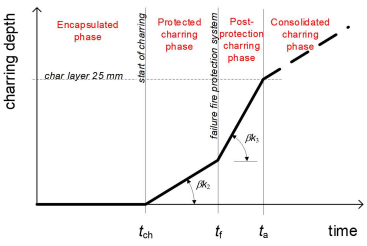
Fire safety

Design of initially protected timber structures

Research on clay plaster as a fire protection system



Proposed design guidelines and equations

Fire part of Eurocode 5

Reference to other studies and clay boards

Full-scale fire tests

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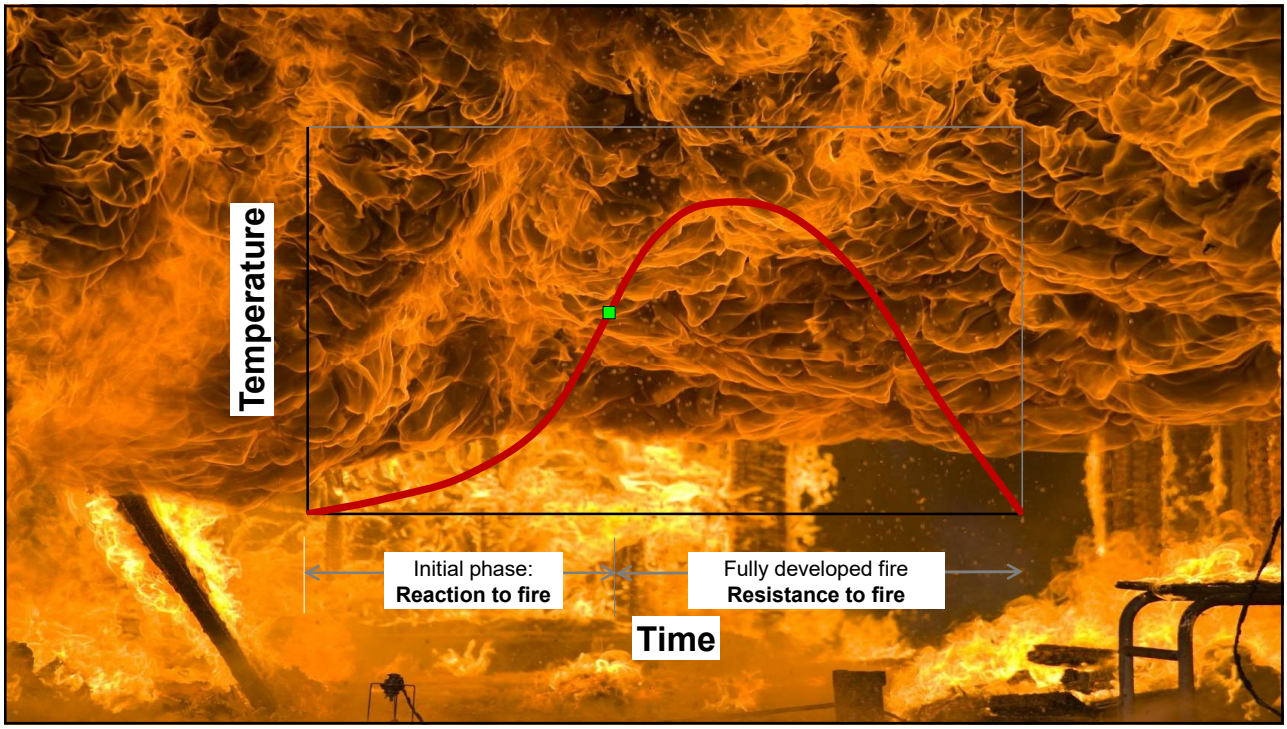

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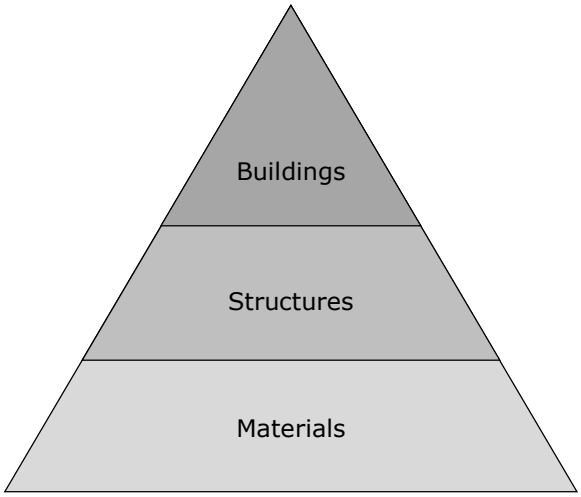
FIRE SAFETY



Building classes

R
REI
EI
} Structural requirements

A1, A2
B, C, D
E, F
} Reaction to fire
Combustibility

TAL TECH

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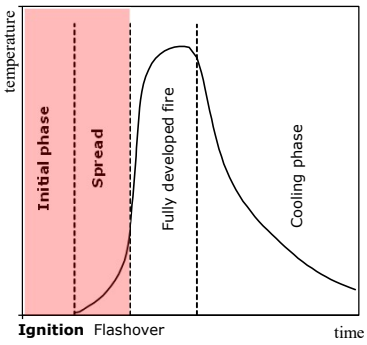
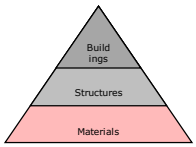
INITIAL PHASE: REACTION TO FIRE





What does it mean?

Euroclass	Contribution to fire
A1	Non Combustible
A2	Limited Combustible No Flashover
B	No Flashover
C	Flashover after 10 minutes
D	Flashover before 10 minutes
E	Flashover before 2 minutes
F	No Performance Determined

Photos: WarringtonFireGent

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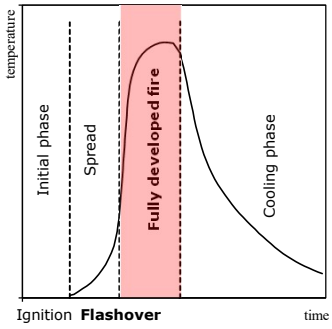
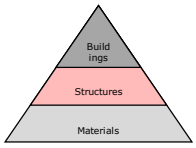
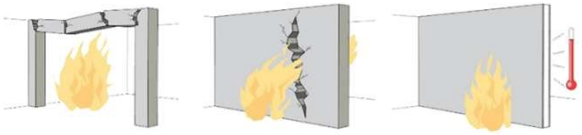
FULLY DEVELOPED PHASE: FIRE RESISTANCE



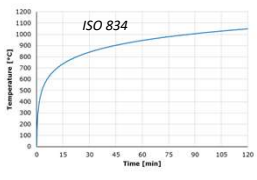




Images: träguiden.se

Load bearing (R) | **Integrity** (E) | **Insulation** (I)

Compartmentation (EI)



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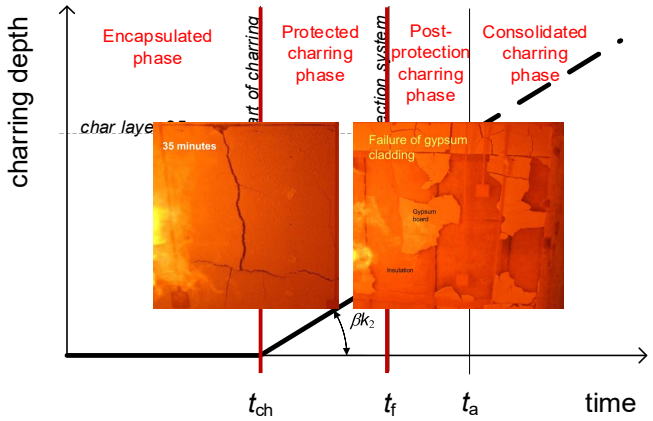
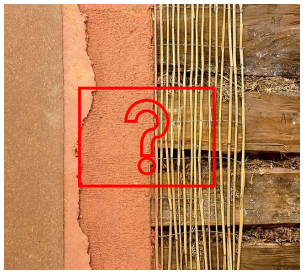
CHARRING PHASES FOR INITIALLY PROTECTED TIMBER





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RESEARCH ON CLAY PLASTER AS FIRE PROTECTION

- Conflict between fire safety regulations and requirements from the heritage board
- Little knowledge on the performance of historic structures in fire
- Little knowledge on clay as a future fire protection material

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CLAY AND LIME PLASTER AS FIRE PROTECTION FOR STRAW BALE BUILDINGS

Fire protection of multi-storey straw bale buildings (2013) Wachtling, J., Hosser, D. & Zehfuβ, J. Research and Applications in Structural Engineering, Mechanics and Computation – Zingoni (Ed.). Taylor and Francis Group, London.

- Furnace tests at TU Braunschweig, Germany
- Encapsulation of $K_2$60 could be achieved with clay board and clay plaster
- The fire resistance of plaster could be improved by certain additives

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RESEARCH ON CLAY PLASTER AS FIRE PROTECTION FOR TIMBER

IN VIEW OF FIRE PART OF EUROCODE 5

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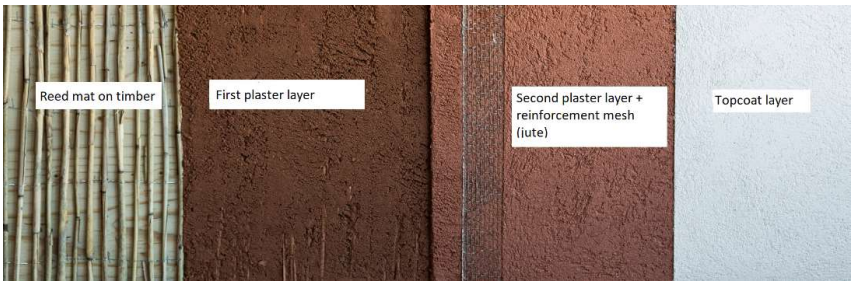
TEST MATERIALS

Plaster system Plaster layer or sequence of plaster layers to be applied to a substrate, including the possible use of a carrier and/or reinforcement



Clay plasters: different fibres (straw, cattail, hemp), grain sizes, products
density class 1.8 according to DIN 18947
thickness: 10 – 44 mm

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SELECTION OF PLASTER SYSTEMS FOR TIMBER STRUCTURES

PLASTER CARRIER: REED MAT

PLASTER SUBSTRATE: REED BOARD 50 mm

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EXPERIMENTAL WORK
TEST METHODS

SMALL SCALE TESTS

INTERMEDIATE SCALE FURNACE TESTS

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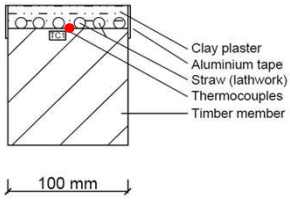
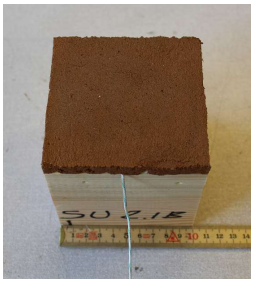
SMALL-SCALE TESTS

- Cone heater of the Cone Calorimeter ISO 5660
- Heat flux values: 50 and 75 kW/m^2
- Test duration: 40 - 60 minutes
- Temperature measurements recorded by thermocouples behind plaster





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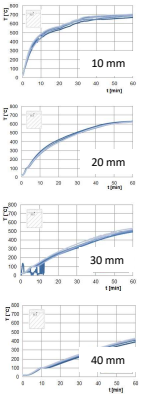
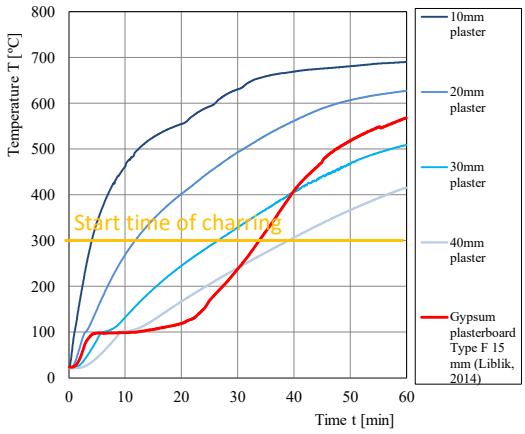
SMALL-SCALE TESTS RESULTS

- Assessment of the heat transfer through the specimen





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EXPERIMENTAL WORK FURNACE TESTS

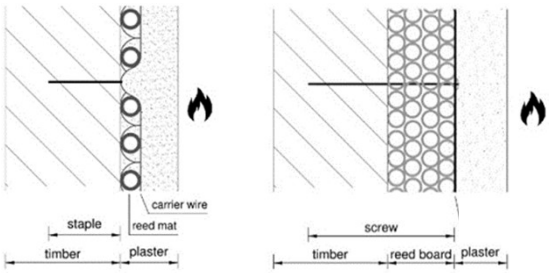
Two main different set-ups of test specimens:

1 – Plaster system applied directly on timber

2 – Plaster system applied on reed board

- **Standard fire exposure conditions**
- 3 different furnaces, max size 1.5 m³
- **11 furnace tests**

- Plaster system thicknesses 10 – 44 mm
- Selected types of plasters (DIN 18947)



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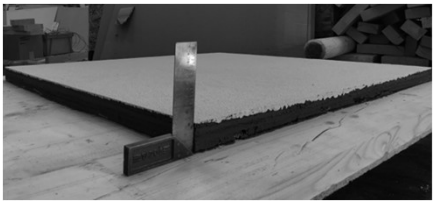
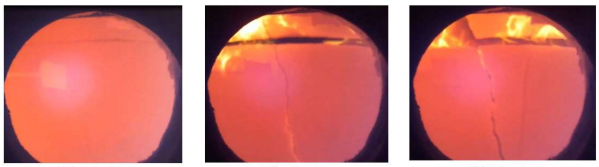
EXPERIMENTAL WORK
FURNACE TEST

- Test orientation: **Vertical**
- Fire exposed area: **950 mm x 950 mm**

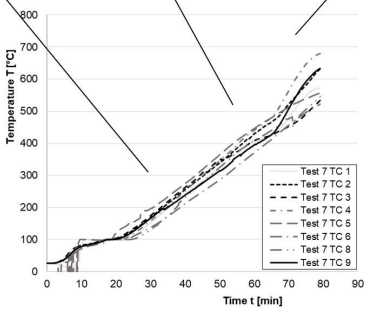


- Performance of clay plaster system:
  - visible crack development in time
  - detachment of thick plaster layers

44 mm **clay plaster system with reed mat** on timber element



28 minutes (First crack) | 60 minutes (Before layer detachment) | 75 minutes (Before the end of test)



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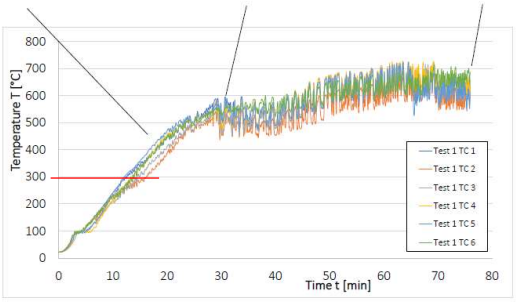
EXPERIMENTAL WORK
FURNACE TEST

- Test orientation: **Horizontal**
- Fire exposed area: **600 mm x 950 mm**

17 mm **clay plaster system with reed mat** on timber element

First crack 19 min | Largest cracks 31 min | Before fall-off 75 min

Start time of charring of timber



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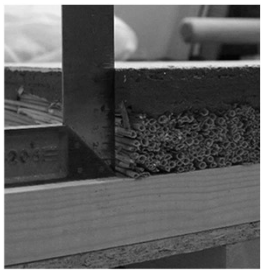
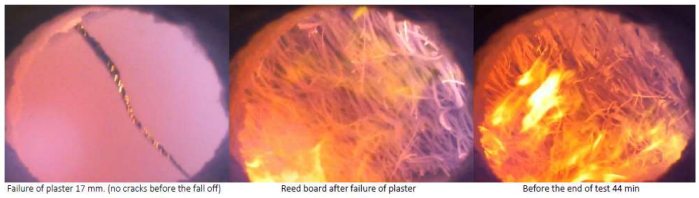
EXPERIMENTAL WORK
FURNACE TEST

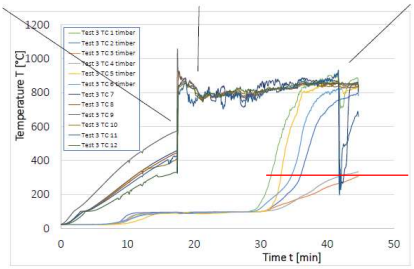
- Test orientation: **Horizontal**
- Fire exposed area: **600 mm x 950 mm**



17 mm **clay plaster system on reed board** on timber element



Failure of plaster 17 mm. (no cracks before the fall off) | Reed board after failure of plaster | Before the end of test 44 min



Start time of charring of timber

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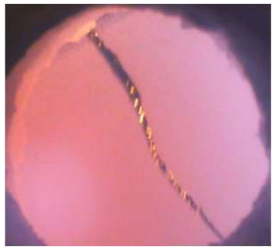
EXPERIMENTAL WORK
FAILURE MODES OF CLAY PLASTER SYSTEMS

1) Failure of the mechanical fastening system

2) Loss of adhesion between the plaster and substrate



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FURNACE TESTS
CHARRING PERFORMANCE OF TIMBER STRUCTURES



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SMALL SCALE METHOD FOR ESTIMATION OF FIRE PROTECTION EFFECT

- **Cone heater test**:

Test specimen: Plaster + Timber

- Plaster thickness 10 – 40 mm
- Timber specimen 100 x 100 x 100 mm

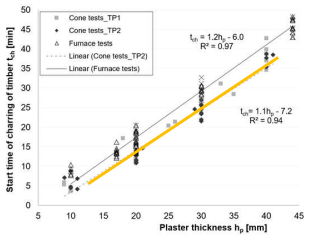
Test duration 40 min (50 and 75 kW/m²)

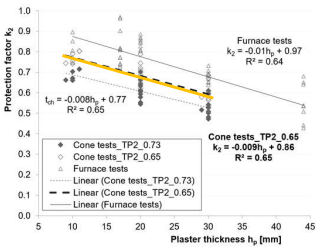
- **Estimation of design parameters**:

t_{ch} – start time of charring

k_2 – protection factor for the protected charring phase (with modification factor)

LIMITATIONS: No failure time





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DESIGN MODEL FOR CLAY PLASTER SYSTEMS
DESIGN VALUES IN VIEW OF FIRE PART OF EUROCODE 5

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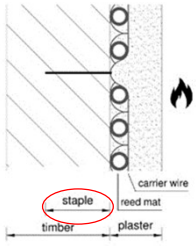
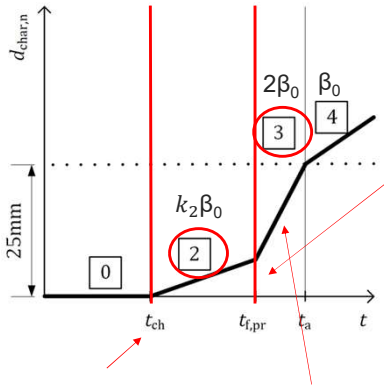
DESIGN EQUATIONS FOR CLAY PLASTER SYSTEMS

- **Plaster system directly applied on timber structures IN WALLS**

$h_p = 10 - 40$ mm





Plaster system with plaster carrier:

$$t_{f,pr} = t_{ch} + \frac{l_f - 10}{\beta_{n,Phase2}}$$

$$\beta_{n,Phase2} = k_2\beta_0$$

$$k_2 = 1 - 0.01 \cdot h_p$$

$$\beta_0 = 0.65\ mm/min$$

Plaster system without plaster carrier:

$$t_{f,pr} = t_{ch}$$

$t_{ch} = t_{prot,0,i} = 1.1h_p - 5.9$

$\beta_{n,Phase3} = k_3\beta_0 = 2 \cdot \beta_0 = 1.3$ mm/min

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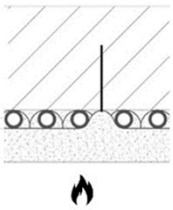
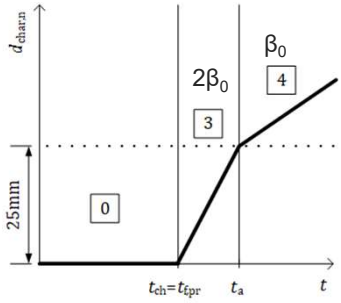
DESIGN EQUATIONS FOR CLAY PLASTER SYSTEM

- **Plaster system directly applied on timber structures <u>with plaster carrier</u> IN CEILINGS**

$h_p = 15 - 20$ mm





$$t_{ch} = t_{f,pr} = t_{prot,0,i} = 1.1h_p - 5.9$$

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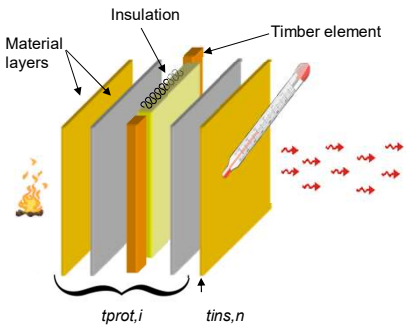
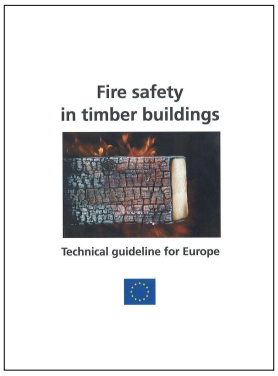
SEPARATING FUNCTION METHOD EI CRITERIA



$$t_{ins} = \sum t_{prot,i} + t_{ins,n}$$



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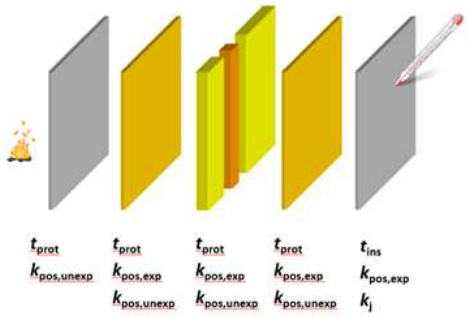
DESIGN VALUES IN RESPECT TO THE REVISED EUROCODE 5 PART 1-2 SEPARATING FUNCTION METHOD



CLAY PLASTER AS FIRE PROTECTION MATERIAL:

$t_{prot,i,0} = 1.1h_p - 5.9$ $= t_{ch}$

$t_{ins,0,n} = 0.6h_p - 3.9$

Position coefficients according to Table 5.2 and 5.3 in FSITB.

FSITB: B. Östman, E. Mikkola, R. Stein, A. Frangi, J. König, D. Dhima, T. Hakkarainen and J. Bregulla, "Fire safety in timber buildings," Stockholm: SP Technical Research Institute of Sweden, 2010.

TAL TECH

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FULL-SCALE TEST
CLAY PLASTER + PLYWOOD ON TIMBER FRAME ASSEMBLY

TAMPERE UNIVERSITY – FINLAND

Test time: 71 minutes
-> No failure of the plaster system
-> No EI performance failure

Plaster system collapsed when extinguishing the test specimen

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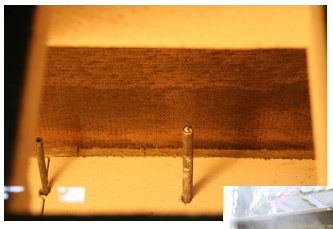
STRAW BALE STRUCTURES WITH CLAY

- Tests in Europe, USA, Australia
- REI60, REI90, REI120



Test with clay board and plaster on chipboard ($K_2$60)
Judith Küppers, TU Braunschweig, Germany

Test was halted at 135 minutes with no failure of the test criteria

Report: Chilt/RF13217/AR1 A fire resistance test performed on a loadbearing compressed straw wall system

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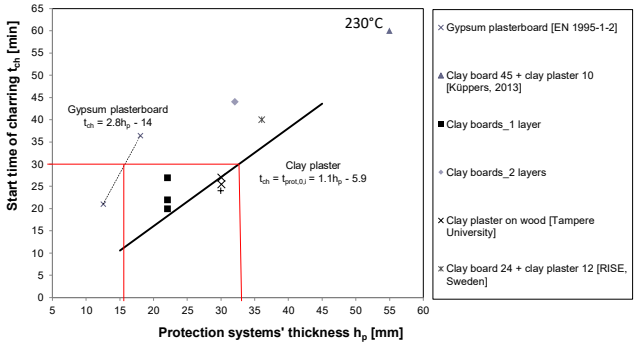
FULL-SCALE TESTS WITH CLAY BOARDS AND PLASTER AS FIRE PROTECTION

Available full-scale test reports

- Clay boards
- Clay board + plaster
- Clay plaster

PROPOSED DESIGN EQUATIONS APPLY ALSO FOR CLAY BOARDS



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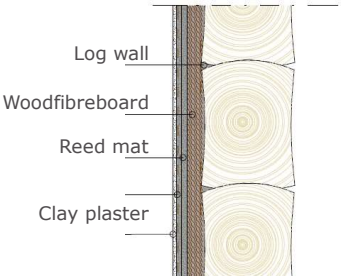
CASE STUDY IN FINLAND
FISKARS VILLAGE




WCTE 2018

RENOVATION OF A WOODEN BUILDING IN A HISTORIC VILLAGE – A CASE STUDY FROM FINLAND

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CONCLUSIONS

- **Composition of plaster**:
  - Tested plasters demonstrated similar performance
  - Additives may increase fire resistance
- **Plaster thickness**:
  - Most significant factor influnecing the charring of timber
  - Detachment of thicker plaster layers
- **Application of plaster onto timber structures**:
  - Plaster carrier and fastening to timber
  - Plaster without plaster carrier
- **FUTURE OUTLOOK:**
  - Different clay boards and combinations with plaster
  - Product development to improve fire protection ability

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THANK YOU

johanna.liblik@taltech.ee

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